

DETERMINATIONS OF THE RIGHT ASCENSIONS OF FIFTY SOUTHERN CIRCUMPOLAR STARS

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A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIRMENTS FOR THE DEGREE OF DOCTOR
OF PHILOSOPHY IN THE UNIVERSITY OF MICHIGAN.

1927



FROM THE
ASTRONOMICAL JOURNAL

FOUNDED BY B. A. GOULD.

No. 888

VOL. XXXVIII

ALBANY, N. Y., 1927, NOVEMBER 7

NO. 2

DETERMINATION OF THE RIGHT ASCENSIONS OF FIFTY SOUTHERN
CIRCUMPOLAR STARS*

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1. HISTORICAL. On joining the staff of the Argentine National Observatory in 1913, the Director, DR. C. D. PERRINE, urged upon me the desirability of determining the positions of the southern fundamental stars, which were generally known to be inferior in precision to those of the northern hemisphere. The new Repsold Meridian Circle, which was hailed by its makers as the last word in modern construction of instruments of that kind, had just been installed and the two new Riefler clocks placed in a constant temperature clock room. It was believed that with such an equipment results could be obtained that would justify the amount of labor that such an undertaking would entail. Before starting the program, however, the errors of the instrument such as division error, pivot error, flexure, etc., were determined and the installation thoroughly tested in order to obtain an idea of just what precision could be expected in the prosecution of the work. The first few series of observations were a revelation of what could be accomplished with such equipment. The results of these test observations convinced me that the projected work would be something more than the mere formation of a star catalog, since it would serve the double purpose of materially strengthening the positions of the southern fundamentals and at the same time would test the then newly formed *Preliminary General Catalog* of PROF. LEWIS BOSS as well as the other fundamental systems in common use. I, therefore, decided to carry out the plan and accordingly observations were begun on the twenty-first of December, 1913, and completed in November, 1923. During this time more than 20,000 observations were made and reduced. Most of the program was completed in 1914.

The object of this paper is to give the newly determined positions of the southern circumpolar stars in advance of the publication of the complete results

in order to satisfy a demand for these places from various sources, and to set forth a few of the more interesting results that have come out of the investigation.

2. PLAN AND SCOPE. The plan of observations in this investigation has been the determination of the places of all stars south of $+30^\circ$ contained in Boss' 1059 Stars, by strictly fundamental methods. The list contained 813 stars. All the time stars were to be observed sixteen times in all, four in each position of the instrument AE, AW, BE, BW where A and B denote the two circles respectively, and E and W the position of the clamp.

The 50 circumpolars between -78° and the pole were to have 16 observations at upper and lower culminations respectively, equally distributed among the four positions of the instrument. All other stars were to have eight observations symmetrically taken with respect to clamp and circle. In practice most of the stars have received more than the assigned number, and for some of the stars the total number of observations is well over 250. No observations were to be used in the fundamental sense except those made during at least three successive nights and the corresponding morning on which the same time stars were observed in order to give true 24 hour clock rates and on which the same circumpolar stars were observed at successive upper and lower culminations for the determination of azimuth independent of the stars' right ascension. Many observations were made that did not fulfil these requirements and, therefore, were not used in the first reduction; but subsequently all the observations were reduced in the same manner since the clock rates were found to remain uniform over long periods of time and since the finally adopted

*A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the University of Michigan.

azimuth was that computed from the mire instead of that actually observed. In order to get upper and lower transits of the same circumpolars at successive culminations it is necessary to observe at or near six o'clock in the evening and morning respectively, since there is no star between -77° and the pole brighter than the third magnitude. For this reason most of the observations have been made between 4 and 9 P.M. or 4 and 8 A.M.

This plan of observing has been advantageous in some respects and disadvantageous in others. It has given very accurate determinations of azimuth but owing to the variation of clock corrections between morning and evening the observations do not lend themselves to the accurate determination of periodic error of right ascension although otherwise admirably fitted to do so, since they were taken at intervals of twelve hours. During the summer when daylight lasts more than 12 hours, one or both transits of the circumpolars as well as the time sets have to be made in full daylight. This is a source of trouble since all observers observe earlier in daylight than with illuminated field during the dark hours. This effect varies considerably for different observers but appears to be constant for any one person. It is difficult to evaluate since it is involved with the diurnal variation of clock corrections as well as with the periodic error of right ascensions.

3. METHODS OF OBSERVING. Although the instrument is provided with a traveling micrometer all transits, with the exception of the circumpolars between -85° and the pole, which were taken by eye and ear, were recorded on the chronograph by tapping the key when the star was seen bisected by one of the wires, — six wires being the minimum for a full transit. The majority of the time stars were taken over the whole reticle of 18 wires. During the first years of preliminary work the so-called impersonal micrometer was thoroughly tested. This device does reduce the personal equation in practically all cases. It does not, however, eliminate it entirely and the part that remains is just as uncertain as with the key method, and in no case are individual signals with the traveling micrometer as accurate as with the key. Although there is a small loss in precision on individual signals with the traveling micrometer, the loss is, in my opinion, more than counterbalanced by the elimination of the greater part of the personal equation. For this reason its adoption for observing the program was seriously considered, but its use had to be abandoned since according to our program the circumpolars had to be observed at many culminations in full daylight where it was found impossible to keep the star

bisected by the moving wire, since in most cases with the faint circumpolars the image was invisible when bisected by the traveling wire.

In order not to complicate the observations with two distinct methods of observing and since for the daylight transits of the circumpolars the traveling micrometer was impossible, the key method was adopted and with no great regret since, in my opinion, where all the observations are to be made by the same observer, the key method is superior.

4. WIRE INTERVALS The instrument is provided with three groups of six wires, each symmetrically spaced. There is a double space in the center of each group and a broad one between them to make identification easy and quick both for observing and for reading the chronograph sheet. The intervals have been determined from all transits north of the zenith. The separate determinations which are usually made from three to four months' observations show no appreciable variation so that in practice the mean of the values resulting from a year's work have been adopted. The mean of the entire ten years could just as well have been adopted since the variations from year to year are extremely minute, demonstrating that the intervals remain fixed over long periods of time. This arrangement of the wires is very advantageous since by utilizing the side groups three stars of almost the same right ascension can be observed on the same night, thus preventing certain parts of the list where the stars are numerous from getting behind the general average. It is also advantageous for the determination of collimation from reversals on circumpolars.

5. COLLIMATION. Usually the circle was reversed every other Monday. At this time determination of the collimation constant was made from the opposing collimators and from readings on the mercury basin. Readings were also made in both positions of the instrument for determining the collimation of the mire. The determinations from the opposing collimators were taken as the basis for definitive values although readings from the mercury are the more accurate. As there has been no change in the collimation for more than ten years the mean of all determinations during that time has been adopted as the definitive value. The instrument is provided with an automatic reversing jack which makes reversals on circumpolars possible. An observer, without assistance, can easily reverse the instrument with entire safety in less than a minute. The values have been used only as a check on the other determinations. Then, too, determinations have been made from time to time with the zenith mirror but these have not proved reliable and,

therefore, its use has been discontinued. The collimation constant is larger than is desirable but as there is no means provided for altering it and in view of the fact that it remains so stable I have adopted it rather than take the chance of making it unstable by providing a means of adjustment. The probable error of one determination is less than $\pm^s.003$. The definitive value which is the unweighted mean of all determinations is $^s.265$, minus for clamp west and plus for clamp east.

6. THE LEVEL. A set of observations was always preceded by micrometer readings on the mercury for level and nadir determinations together with setting on the mire for azimuth control. The settings were repeated at intervals of about two hours thereafter and the set closed with similar determinations. The readings on the mercury in conjunction with the collimation give the true level correction. The value of the micrometer screw is $4^s.0782$. From time to time the level thus derived was checked by means of the hanging level, but since the determinations from the mercury are so much more accurate they have been used in all cases for the reductions of the observations. The adopted level constant for a set of observations resulted from the mean of the determinations made simultaneously with the observations except in a few isolated cases when a rate was applied where the separate determinations clearly indicated a progressive change of $^s.02$ or more.

7. THE MAGNITUDE EQUATION. The instrument is provided with a series of screens and diaphragm operated by the observer at the eye end while taking the transits. It was the plan to reduce all stars in so far as possible to the fourth magnitude by applying the appropriate screen or diaphragm. The values of these were determined by observing the same star over one set of wires with screen and the following without, or vice versa. The values of the screen and diaphragm were accurately determined since many stars were thus observed each night. From the deduced values of the screens and diaphragm, the effect per magnitude was easily found. There was no need to determine the equation over a wide range since only the differential effect was necessary after applying the value of the screens as all stars of the list, with few exceptions, were brighter than the sixth magnitude. The adopted value of the magnitude equation for correcting the observed transits was $-.010 (M - 4 \text{ mag.})$

8. EFFECT ON OBSERVATIONS DUE TO THE DIRECTION OF MOTION OF TRANSIT. Observations were found to be recorded uniformly later when transiting from right to left through the field of the instrument than when transiting from left to right. This point

was tested by means of a reversing prism. Groups of about ten stars for each 10 degrees of Declination between the zenith and the pole were selected and observed in the following manner. The first group of six wires were observed direct. The prism was then rotated so that the middle group appeared to be observed in the reverse direction, alternating for each star in the program. A large number of such observations were made and the means of Direct-Reversed taken for each 10° of Declination. There appeared to be no dependence on Declination so the mean of all was adopted as the most probable value. A correction of $-.062$ was therefore applied to all transits between the zenith and the pole. Stars at lower culmination are not affected since they transit in the same direction as stars north of the zenith. Transits taken with the traveling micrometer were not investigated but they are undoubtedly affected in the same manner. Nearly every one who measures star images on photographic plates has a systematic difference between direct and reversed settings. It is, therefore, logical to assume that transits with the traveling micrometer would be affected by such a bisection error.

9. ERRORS OF THE PIVOTS. The errors of the pivots, as stated above, were investigated and the detailed results set forth in a paper before the Second Pan American Scientific Congress. There is no need for repetition here. For convenience, however, the following table of corrections is given, in order to facilitate the application of this correction to the given places in case occasion should arise to do so. No correction for error of pivots has been applied.

For convenience they have been expressed in seconds of time at the Equator.

Azimuth component, clamp west	Level component, clamp west
$0^\circ -^s.005 \sin \zeta \sec \delta$	$+^s.006 \cos \zeta \sec \delta$
15 + .002	+ .001
30 + .000	- .003
45 - .000	- .002
60 + .003	- .003
75 - .002	- .003
90 + .000	- .005
105 - .005	+ .002
120 - .005	- .001
135 - .003	+ .001
150 + .001	- .001
165 + .002	+ .004
180 + .003	- .001
195 + .001	+ .003
210 - .001	+ .001
225 + .001	+ .001

Azimuth component, clamp west	Level component, clamp west
240° + ^s .001 sin ζ sec δ	+ ^s .003 cosin ζ sec δ
255 + .002	+ .002
270 + .001	- .003
285 + .002	- .003
300 + .005	- .007
315 + .002	- .001
330 + .003	+ .004
345 - .001	+ .004

In the azimuth component plus indicates that east pivot points south of east. In the level component plus indicates that same pivot is too high.

10. AZIMUTH. The azimuth has in all cases been determined from the fully corrected transits of successive upper and lower culminations of the close circumpolars. The resulting azimuths were, therefore, independent of the star's right ascension. This is a necessary measure in the southern hemisphere owing to the uncertainty in the positions of the southern circumpolars. A series of observations usually had from two to ten circumpolars available for the determination of azimuth. The mean of all the azimuths of the series thus deduced was taken and assumed to correspond to the mean of all the micrometer settings on the mire made during the series. Knowing the collimation of the mire and the azimuth of the instrument, the azimuth of the mire was easily deduced. These weekly values of the mire's azimuth were tabulated and the mean taken. This final value which was the mean of all the determinations made during a year was adopted as the true azimuth of the mire for that period, and from this value instantaneous azimuths were computed for the reductions of the observations of the year.

The following table gives the weekly determinations of the mire's azimuth for the first year's observations together with the adopted mean for the period and the difference between observed and computed azimuths. These differences show a slight tendency towards periodicity as they should since the azimuth of the mire should have a variation caused by the variation of the latitude. This has not been taken into account in this investigation and it is doubtful whether its inclusion in the most refined reduction would be justified.

AZIMUTH OF THE MIRE

1915-1916	wt.	Az. of mire s	O - C s
Dec. 21 to Dec. 29	7	.475	+ .014
26 to Jan. 1	19	.480	+ .020

1915-1916	wt.	Az. of mire s	O - C s
Jan. 4 to Jan. 8	9	.476	+ .013
11 to 12	3	.450	- .016
18 to 20	5	.464	+ .002
25 to 27	8	.476	+ .016
26 to Feb. 1	7	.464	+ .004
Feb. 7 to 12	12	.468	+ .004
14 to 18	7	.447	- .013
21 to 26	15	.467	- .003
27 to Mar. 4	24	.461	- .001
Mar. 8 to 10	7	.439	- .027
28 to Apr. 1	19	.474	+ .014
Apr. 4 to 12	22	.467	- .003
20 to 21	3	.453	- .007
May 2 to May 6	28	.443	- .017
8 to 13	25	.464	+ .002
15 to 17	10	.455	- .005
22 to 26	11	.455	- .007
June 6 to June 10	10	.452	- .008
12 to 17	27	.449	- .011
19 to 21	7	.456	- .010
26 to 30	25	.470	+ .004
July 2 to July 7	15	.454	- .008
14 to 16	14	.437	- .023
17 to 19	8	.479	+ .019
20 to 23	8	.469	+ .007
27 to Aug. 4	5	.492	+ .026
Aug. 8 to 12	12	.463	+ .003
15 to 20	19	.490	+ .024
21 to 26	11	.464	+ .004
28 to 31	6	.477	+ .011
Sept. 2 to Sept. 9	13	.472	+ .012
11 to 13	3	.469	+ .009
14 to 16	3	.467	+ .001
18 to 23	11	.455	- .007
25 to 30	12	.459	- .007
Oct. 9 to Oct. 14	7	.473	+ .013
16 to 18	7	.468	+ .008
23 to 28	13	.460	- .000
Nov. 2 to Nov. 4	2	.476	+ .010
7 to 11	3	.459	- .003
13 to 16	2	.465	- .001
20 to 24	5	.466	+ .006
Dec. 4 to Dec. 9	2	.431	- .019
26 to 30	6	.449	- .013
		.463	±.0102 p. e.

The column O - C above is the difference between observed and computed azimuths. The probable error of a difference is ±.0102 from which we easily

deduce that the probable error of an azimuth used for the reduction of the observations was $\pm^s.007$.

11. THE MIRE. The mire is situated to the south at a distance of 130 meters from the instrument. It is of the usual type, having a metal plate perforated by a small circular hole which is illuminated by an electric lamp. The instrument is provided with a small lens placed just in front of the reticle which can be raised or lowered by means of a thumb screw on the side of the micrometer box. When raised into position the mire is brought into focus. It forms a splendid image in the field of the telescope about like that of a 4th mag. star when the seeing is good. This arrangement is very simple and has given entire satisfaction as the tabulated results for 1916 show. It is very advantageous, especially in fundamental work, to have a mire of such stability since the azimuth of the instrument can be obtained from it for any instant even though no circumpolars have been observed at that time.

12. CLOCK CORRECTION. The clock corrections used in the reductions of the stars in this paper were obtained in the following manner. The corrected transits of the time stars were subtracted from the right ascensions of the stars reduced to the beginning of the year. Four groups of corrections were formed — one for the observations made during full daylight just before sunset and one for those made with illuminated field during the early hours of the night, and two similar ones were obtained from the morning observations. Except in cases where it was impossible to get observations, each group contained at least four time stars and in many cases a group had as many as twenty. The clock rate was assumed to be constant for the series. Each group mean was then subtracted from the mean of the same stars observed twenty-four hours later, or multiples thereof, in order to get the true twenty-four hour rate. The adopted clock correction for any group was found by combining all the daily group means obtained during the week without regard to weight. With the adopted twenty-four hour clock rate and with the adopted clock correction for the group, corrections were then computed for each star in that particular group and when applied to the corrected transit gave the observed right ascension. By this method all systematic difference between day and night observations, as well as evening and morning, was completely eliminated from the resulting positions. Each circumpolar when observed above pole was reduced with a clock correction obtained from a group of time stars having approximately the same mean right ascension, while the same star when ob-

served below pole was reduced with a correction from stars twelve hours distant. As each star received very nearly the same number of observations above as below the pole the periodic error of the Boss System was also eliminated from the resulting places. In all cases, the final place for each star is that resulting from combining the means of observations above and below the pole without regard to the number of observations that make up the respective means. This method of eliminating systematic differences is complete; but tends slightly to increase the calculated probable error of a single observation since the whole effect enters as probable error. •

13. DAY-NIGHT OBSERVATIONS. From the first it was noticed that a clock correction determined in full daylight differed systematically from one determined with illuminated field. This difference, as stated above, is a difficult quantity to determine with certainty, since it is complicated with the periodic error of right ascension and the diurnal variation of clock rate, the nature of which, at present, is not well understood. To illustrate, the results of the first year's work are given below. The following quantities in column O are the differences between the adopted clock corrections for weekly series determined from the afternoon and early evening observation, reduced to the same instant with the mean twenty-four hour clock rates.

DIFFERENCE BETWEEN DAY-NIGHT OBSERVATIONS
1915-1916

		Observe "Z"		C — O
		O	C	
		^s	^s	^s
Dec.	29	+.012	— .001	— .013
Jan.	12	— .007	— .011	— .004
	26	— .010	+.004	+.014
Feb.	8	— .003	+.002	+.005
	11	— .016	— .000	+.016
	23	+.014	+.018	+.004
Mar.	9	+.008	+.007	— .001
Apr.	11	+.025	+.012	— .013
May	4	+.046	+.044	— .002
	16	+.055	+.049	— .006
June	8	+.055	+.057	+.002
	20	+.045	+.033	— .012
	28	+.023	+.037	+.014
July	15	+.032	+.046	+.014
Aug.	4	+.028	+.025	— .003
	18	+.043	+.027	— .016
	30	+.029	+.029	— .000
Sept.	14	+.055	+.044	— .011
	28	+.012	+.021	+.009

		Observer "Z"		C - O
		O	C	
		s	s	s
Oct.	3	+0.053	+0.037	-.016
	6	+0.015	+0.022	+.007
	17	+0.026	+0.033	+.007
Nov.	2	-.020	+0.017	+.037
	15	+0.035	+0.006	-.029

p. e. $\pm .0098$

		Observer "G"		C - O
		O	C	
		s	s	s
Dec.	23	-.034	-.019	+.015
Jan.	6	-.021	-.014	+.007
	19	-.029	-.030	-.001
Feb.	1	-.037	-.028	+.009
	17	-.017	+.004	+.021
Mar.	2	-.014	-.009	+.005
	30	-.003	-.001	+.002
Apr.	20	+.022	+.020	-.002
May	10	+.032	+.020	-.012
	24	+.022	+.021	-.001
June	15	+.049	+.038	-.011
July	6	-.001	+.029	+.030
	22	+.017	+.021	+.004
Aug.	10	+.028	+.033	+.005
	23	+.069	+.031	-.038
Sept.	6	+.027	+.036	+.009
	20	+.026	+.023	-.003
Oct.	12	+.017	+.024	+.007
	26	-.008	+.005	+.013
Nov.	9	-.010	-.002	+.008
	22	+.010	-.004	-.014
Dec.	9	+.028	-.004	-.032
	29	+.001	-.019	-.020

p. e. $\pm .0106$

If we let Δt_0 be the true clock correction and Δt_1 and Δt_2 the mean clock corrections as determined in the late afternoon and early evening and assume that the time stars of Boss' system have periodic errors of the form

$$a \sin a + b \cos a + c \sin 2a + d \cos 2a$$

each of the above quantities will be rigorously represented by the following equation:

$\Delta a = a \sin a + b \cos a + c \sin 2a + d \cos 2a + e + f$ where e is the constant difference between observations made in daylight and with illuminated field and f a constant to reduce clamp west to that of clamp east. Each Δa formed a conditional equation of the above form. These were solved by the method of least squares, separately for each observer.

The resulting coefficients are given for each observer together with the two constants e and f

	a	b	c	d	e	f
Z	+.0316	-.0149	+.0009	-.0053	-.0168	-.0140
G	+.0361	-.0250	+.0015	-.0056	-.0060	-.0101

The quantities in the column O were found by substituting these values in the conditional equations. The residuals in column C - O show how well the formulæ represent the observations. From this we deduce that the probable error of a clock correction used in the reductions of the observations of the stars in this paper is $\pm .007$. This indicates that there are still some systematic errors present as the mean clock corrections should have had a slightly smaller probable error, since from the discussion of more than 3000 residuals in 1917-1918, the purely accidental probable error of the clock correction from a single star is slightly less than $\pm .010$ sec δ .

The constant difference between day and night observations as well as the part depending on the position of the clamp are considered well determined since almost identical values result from other years' work by a method completely different from that used here. The coefficients which express the periodic error of Boss' system are in no sense to be taken as definitive. The arcs from which they were determined were too short to give accurate values, especially for the terms in $\sin a$ and $\cos a$.

Part of the program left in 1916 was completed between Feb. 6 and Nov. 22, 1923. During this period the clock corrections were almost completely symmetrical with respect to daylight and illuminated field both in the evening and morning. They were, therefore, well fitted for the determination of periodic error of right ascension of the time stars since the Day-Night effect could be eliminated by taking the mean of the two clock corrections thus determined. The only other difference in these clock corrections was that resulting from their variation when determined at different hours of the day.

If we assume this difference to be constant (an hypothesis not at all likely) we could represent the difference between a Δt of the evening and a Δt of the morning by an equation of the following form:

$$\Delta t_e - \Delta t_m = a \sin a + b \cos a + c \sin 2a + d \cos 2a + e$$

where e here denotes the systematic difference between a Δt determined in the evening from one determined in the morning.

The normals were formed and solved with the following results:

a	b	c	d	e
$\pm .0118$	$\pm .0009$	$-.0265$	$\pm .0021$	$\pm .0066$

From this solution the coefficients a and b and the constant e are well determined but those of c and d are weak in comparison. The constant e is much smaller for this series than that resulting from previous years, but consistent with respect to sign.

Owing to the uncertainty in the variations of Δt s determined in the evening and morning no attempt is made at this time to represent the true periodic errors of Boss' system. That is held in abeyance till the revision of the time stars has been effected.

It is interesting to note in passing the two formulas found by HOUGH at the Cape. The first was given in the *Observatory* for February 1913, and the second in the *Cape Second Fundamental Catalog* for 1900.

A_1	A_2	B_1	B_2
$+^s.0106$	$-^s.0078$	$+^s.0022$	$-^s.0096$
$+^s.0179$	$-^s.0077$	$+^s.0057$	$-^s.0017$

14. MORNING-EVENING OBSERVATIONS. In 1913 it was discovered that clock corrections determined at or near 6 A. M. were systematically smaller than those determined at 6 P. M. This has been discussed in detail in this journal. It has also been discussed at length by PROFESSOR TUCKER in *Lick Observatory Bulletins* and by PROFESSOR VARNUM in this journal and the *Astronomische Nachrichten*. PROFESSOR VARNUM has worked out an explanation on the theory of differential refraction and in a recent number of the *Lick Observatory Bulletins*, PROFESSOR TUCKER finds some evidence in support of such a theory.

I have tried during the last ten years to find a solution to the problem along such lines but must confess failure since for the Córdoba observations, at least, no theory yet advanced is adequate to explain the observed difference. For the Córdoba observations the differences do not depend on Declination or Zenith Distance as they would have to do according to any theory of refraction.

This is clearly shown in the following table taken from the results in *A. J.* No. 745 where the mean differences between evening and morning are arranged according to Declination.

Zone	Diff.	Zone	Diff.
°	° s	°	° s
+30 to +20	.038	-20 to -30	.040
+20 to +10	.049	-30 to -40	.038
+10 to 0	.053	-40 to -50	.042
0 to -10	.040	-50 to -71	.042
-10 to -20	.042		

The circumpolar stars in this paper are still better fitted to show whether this effect is a function of declination or not, since if there is a shift of the meridian

caused by refraction the effect at or near the pole will be increased by $\sec \delta$.

The remarkable stability of the mire as shown in a preceding paragraph together with the large number of observations of the circumpolars at upper and lower culmination enables us to test this point once for all.

If there is a shift of the meridian due to refraction, azimuths computed in the ordinary way (the Δt being known) from evening observations should be too large for both above and below pole and too small from the morning observations. If then we compute the azimuth of the mire from the instrumental azimuth as determined from the single culminations of circumpolars of the evening and again the following morning from observations of the same stars, we should have an excellent way of detecting the differences due to refraction since we should get double the difference.

A single example will suffice to show this in detail.

AZIMUTH OF MIRE

		Evening	
		κ Oct.	L 634 S.P.
		s	s
June	26.25	0.474	0.436
	30.25	.488	.446
July	4.25	.491	.530
	5.25	.433	.484
	6.25	.459	.477
	14.25	.499	.446
	15.25	.489	.408
	17.25	.468	.413
	18.25	.445	.494
	21.25	.478	.473
	22.25	.395	.477
mean		.465	.462

		Morning	
		κ Oct. S.P.	L 634
		s	s
June	29.75	0.459	0.485
	30.75	.426	.478
July	4.75	.572	.445
	5.75	.454	.403
	6.75	.351	.424
	14.75	.399	.462
	15.75	.430	.515
	17.75	.525	.529
	18.75	.485	.456
	21.75	.479	.408
	22.75	.529	.495
		.464	.464

Evening	.464 p.e. $\pm .006$
Morning	.464 p.e. $\pm .006$

From this we find the probable error of a determination of azimuth from a single culmination (upper or lower) to be $\pm 0^s.019$.

The two stars *Kappa Octantis* and *L 634* which have approximately the same declination (-85°) and separated almost exactly by twelve hours in right ascension are especially well fitted for this purpose. There are several other pairs almost as good but with smaller declination. All stars observed at successive culminations concur in showing that there is no systematic error introduced into the azimuths from the effects of refraction.

The evidence presented here is conclusive and disposes of the refraction theory once for all so far as this series of observations is concerned. These observations are affected by a constant systematic difference which can be none other than a diurnal variation in clock error as that is the only correction that enters into meridian circle reductions as a constant for all declinations.

The nature of the diurnal variation is still unknown but it is almost certainly intimately related to the annual rate which has been found to have large periodic variation depending on double the Sun's longitude and which is absolutely impossible to explain on any theory of refraction.

15. ANNUAL CLOCK RATES. In the early part of 1919 the two Riefler clocks Nos. 155 and 330 were permanently installed in the new subterranean clock room. This room has been fully described in the columns of the *Astronomical Journal*, but the essential details are given here.

The room which is constructed of reinforced concrete made impervious to water or moisture by a waterproofing mixture is situated at a depth of ten meters below the surface of the ground and directly underneath the main hall of the new Observatory building. The experiments of the Argentine Weather Bureau conducted over a period of many years show that all daily variation of temperature disappears at a depth of 50 cm. and at a depth of ten meters the temperature is constant the year round. By taking advantage of this condition we have avoided the necessity for all cumbersome devices such as thermostats, electric heaters, etc., for maintaining constant temperature which, at best, in practice rarely succeed in keeping the temperature within a tenth of a degree on either side of the mean. The Riefler clock is extremely sensitive. Changes of a tenth of a degree when the case is hermetically sealed are sufficient to produce

corresponding changes in the rate. No such variations of temperature occur in the Córdoba clock room. The temperature is absolutely uniform. Unfortunately, Córdoba is visited by rather frequent earthquake shocks some of which are of sufficient intensity to stop the clocks, but between such disturbances the clocks are never touched as no one enters the room. The heavy iron doors both at the bottom and top of the tube leading to the room are clamped tightly on the lead gaskets, which makes the room almost as hermetically sealed as the cases of the clocks themselves, which are, of course, absolutely air tight. Experiments have shown that whenever the clocks suffer disturbances even though they be of the most trivial nature, nearly a month is required for them to settle down to uniformity again, and in all cases the rate after the disturbances will be different from that before. Thus, only by placing the clocks under constant conditions can uniform rates be obtained. The frequent changing of the pressure in the clock case to make the rate conform to a straight line destroys all hope of detecting annual periodic variations.

From September 1919 to October 1920, the clocks ran without any known disturbances. It was shown in this *Journal*, No. 815, that the observed clock corrections during this period could be accurately represented by the following formula:

$$-16^s.495 - ^s.0811 t + ^s.0001902 t^2 + ^s.3172 \sin 2 \odot - ^s.2303 \cos \odot + ^s.0205 \sin 5 \odot - .0567 \cos 5 \odot = \Delta t$$

The probable error of the difference between the observed clock corrections during the year and those computed from the formula was $\pm ^s.024$ which is about as accurate as a clock correction can be determined without first eliminating the periodic errors of right ascension and accidental errors of individual star places. From this we are led to the conclusion that the corrections deduced from the formula for any instant during the year actually represent the true correction of the clock better than the observed one.

Again in 1923 we had a period between February 6 and November 22 during which the clocks were undisturbed by any known causes and again the rate was found to depend on the longitude of the *Sun* as in the formula found above.

The following formula was found from a treatment of the data similar to that in the article mentioned:

$$-4^s.690 + ^s.0569 t - ^s.0001247 t^2 - ^s.1826 \sin 2 \odot + ^s.1653 \cos 2 \odot - ^s.0311 \sin 4 \odot + ^s.0354 \cos 4 \odot = \Delta t.$$

This formula represents the observed clock corrections with the same exactitude as in the other year.

From a consideration of the results of these two years' observations it would appear that the rate of the clocks when undisturbed is always a function of the longitude of the *Sun*. This supposition is greatly strengthened by the fact that both clocks traced out almost identical curves in both cases. No explanation of its cause can be given at this time. It cannot, of course, be due to refraction. A shift in the meridian sufficient to produce three tenths of a second of time at the equator would be sufficient to make a difference of more than 40 seconds between upper and lower culminations of a star like *Sigma Octantis* with declination of more than 89° , but as shown above there is no difference at all. It was shown in a preceding paragraph that the observed differences between clock corrections made near sunrise and sunset were due to diurnal variation of clock rate. Since the annual

periodic variation is a function of the *Sun* and since the diurnal variation appears also to be a function of the *Sun* it seems logical to assume that the two are closely related and probably due to the same cause. The problem will be fully investigated, but owing to the difficulty Córdoba experiences in getting long series of observations without disturbances from earthquake shocks it may be a long time before the problem can be solved. Owing to the important part the annual variation of clock rate, as well as the variation of clock corrections made near sunrise and sunset, plays in fundamental meridian circle work and the interchange of time signals by wireless, it seems to me that it is desirable that all observatories that make a practice of making accurate time determinations should co-operate in investigating the cause of the phenomenon.

16. THE RIGHT ASCENSIONS OF 50 SOUTHERN CIRCUMPOLAR STARS REDUCED TO 1900 WITH BOSS' PROPER MOTIONS.

Stars	R.A.	Dec.	Cordoba -Boss	Cape -Boss	San Luis -Boss*
	h m s	° '	s	s	s
L 9756	0 5 30.582	-82 47	+ .252	+.088	+ .207
α Oct	0 12 30.753	-88 55	+1.398	+.600	+2.000
β Hydri	0 20 30.213	-77 49	+ .198	+.101	+ .130
L 505	1 32 59.368	-79 1	+ .345	+.105	+ .419
L 634	1 43 8.589	-85 16	+ .499	+.409	+ .487
μ Hydri	2 33 47.270	-79 33	+ .326	+.082	+ .296
δ Mens	4 24 44.141	-80 27	+ .319	+.330	+ .393
ν Mens	4 29 49.250	-81 48	+ .130	+.269	+ .195
ξ Mens	5 10 15.085	-82 36	+ .595	+.520	+ .691
L 2512	6 6 9.790	-85 56	+ .280	+.17	+ .299
ζ Mens	6 48 22.516	-80 42	+ .178	+.254	+ .068
L 3274	7 22 1.53	-86 52	+ .037	+.16	- .020
L 3911	7 53 2.752	-88 34	+1.192		+ .928
θ Cham	8 23 38.931	-77 10	+ .252	+.149	+ .163
η Cham	8 44 43.900	-78 36	+ .255	+.105	+ .219
ζ Oct	9 11 14.620	-85 16	+ .192	+.18	- .069
ζ Cham	9 36 50.176	-80 29	+ .229	+.253	+ .152
μ Cham	10 3 24.476	-81 44	+ .254	+.152	+ .094
γ Cham	10 34 17.418	-78 5	+ .076	-.094	.000
L 4510	10 36 55.398	-85 34	+ .238	+.27	+ .151
δ^2 Cham	10 44 51.013	-80 1	+ .195	+.184	+ .172
η Oct	11 0 1.291	-84 3	+ .111	+.16	+ .070
β Cham	12 12 28.785	-78 45	+ .351	+.217	+ .223
L 5235	12 40 0.94	-89 15	+1.360		- .812
ι Oct	12 44 27.615	-84 35	+ .615	+.33	+ .331

Stars	R.A.	Dec.	Cordoba -Boss	Cape -Boss	San Luis -Boss*
	h m s	° ' "	s e	s	s
κ Oct	13 24 42.308	-85 16	+ .188	+.07	+ .113
δ Oct	14 10 51.694	-83 13	- .006	-.06	+ .129
α Apod	14 35 25.818	-78 37	+ .340	+.171	+ .255
L 5823	14 38 0.61	-87 48	+ .731		+ .033
ρ Oct	15 20 11.979	-84 8	+ .429	+.32	+ .224
δ Apod	16 5 23.859	-78 27	+ .283	+.046	+ .080
γ Apod	16 18 6.216	-78 40	- .021	+.180	- .091
L 6545	16 23 34.939	-86 11	+ .329	+.22	+ .262
β Apod	16 28 47.443	-77 18	+ .050	-.067	- .027
L 7088	17 12 45.073	-80 46	+ .006	+.003	+ .027
L 7078	17 29 0.221	-85 11	+ .581	+.44	+ .392
χ Oct	17 56 4.352	-87 40	- .328	-.11	- .110
σ Oct	18 59 44.749	-89 15	+1.039	+.62	+1.683
L 8094	19 37 37.057	-81 36	+ .469	+.472	+ .464
L 8331	20 16 39.567	-81 18	+ .662		+ .565
α Oct	20 52 36.793	-77 24	+ .300	+.065	+ .185
ν Oct	21 30 22.029	-77 50	+ .235	+.068	+ .268
λ Oct	21 35 36.579	-83 11	+ .469		+ .473
L 6460	21 37 41.82	-89 19	+3.000		+2.617
ϵ Oct	22 8 49.933	-80 56	+ .628	+.625	+ .573
ν Oct	22 12 35.328	-86 29	+ .348	+.31	+ .572
β Oct	22 35 51.278	-81 54	+ .352	+.259	+ .273
τ Oct	23 13 10.552	-88 2	+1.202	+.60	+ .827
γ^1 Oct	23 46 15.081	-82 34	+ .497	+.347	+ .419
θ Oct	23 56 27.834	-77 37	+ .334	+.058	+ .170

* The San Luis values were sent to me by PROFESSOR VARNUM after my return to Cordoba. They are published by permission of PROFESSOR BOSS.

17. THE RESULTS. It is somewhat surprising to find that the southern circumpolars of Boss' *Preliminary General Catalog* require such large systematic corrections. The accidental errors, too, are larger than was to be expected. These corrections are, however, well supported by the results of the first and second Fundamental Catalogs of the Cape for 1900, as shown in column five. The indicated systematic correction to Boss from the Córdoba results is about a tenth of second larger than that from the Cape results. This may mean that the corrections are getting larger with the lapse of time since the mean epoch of the Córdoba observations is five years or more later than that corresponding to the observations at the Cape. The Cape results do not depend directly on azimuths from consecutive upper and lower transits of the same circumpolars but involve the use of tabular places. Whatever errors were in the tabulated places would to a

large extent be reproduced in the new positions. It is possible that part of the difference comes from that source. It is hard to see how there can be any uneliminated instrumental errors in the Cordoba results since all stars were observed symmetrically as to clamp and at upper and lower culmination.

The difference between the mean of the above pole and the below pole observations is $^s.012$. This indicates that the instrumental constants used have been such as to make the axis of the instrument coincide with the true meridian passing through the pole. But be that as it may, there can be no doubt that the positions of the circumpolars as tabulated in Boss' *Preliminary General Catalog* require large systematic corrections that increase rapidly as the pole is approached. This, undoubtedly, came about through defective collimation corrections and insufficient care in the determination of azimuth from consecutive

upper and lower culminations of the same circumpolar stars in the southern catalogs that formed the basis of Boss' system. The series of fundamental observations made at San Luis under the direction of Prof. LEWIS BOSS in 1909-1910 should considerably strengthen the positions of the southern fundamental stars but there still remains an urgent need for first class fundamental work in the southern hemisphere. This places a strong obligation on those observatories equipped to do first class fundamental work to continue the programs for several years to come.

18. SUMMARY. 1. There is a well defined systematic difference between transits made in full daylight and those made with illuminated field. For all observers transits are recorded earlier in daylight than in darkness by a quantity that varies quite widely with observers but remains remarkably constant for any one person.

2. The variation in clock corrections near sunrise and sunset discovered at the beginning of the work has been shown to be constant for stars of all declina-

tion. This is essentially the same as a variation of clock rate no matter what the cause.

3. The Riefler clock appears to have a well defined annual periodic variation of rate depending on the longitude of the *Sun* whenever allowed to run for long periods of time undisturbed. This appears to be closely related to the diurnal variations of clock corrections near sunrise and sunset. Both are undoubtedly produced by the same cause.

4. It is surprising to find that the circumpolar stars require such large systematic corrections. If the Córdoba results actually represent the true places of the stars on the celestial sphere, then the circumpolars in Boss' list require a systematic correction of $+^s.31$.

The Córdoba positions are not to be considered definitive as they are still subject to some small refinements. The final places will probably not differ appreciably from those given above.

Ann Arbor, Michigan,
1927.

